THE GREAT FLOOD IN THE TISZA BASIN IN 1970

M. ANDÓ and I. VÁGÁS

Department of Natural Geography Attila József University, Szeged; Water Anthorily, Szeged

(Received January 15, 1972)

Abstract

In May and June 1970 an extraordinary flood passed through the Tisza and all the left-side tributaries of the Tisza. The highest flood levels recorded so far were overstepped at least in half metre order and in the tributaries in metre order and even in the order of more metres by the flood level. The inundation devastated in some regions, as known; causing catastrophic disasters.

The paper is establishing that the extraordinary hydrome teorological situtaions and the orographic data of the watershed area can be considered as a primary effect exerting the flood situation.

The series of current waves that developed in 1970 were characterized by that the water-movement of the rivers of the water system and the common order of the inundation periods differed from the regular ones accustomed to under average circumstances.

The movement of water in the Tisza is generally characterized by three flood waves a year.

1970 all that happened in another way. Until the end of April, five flood waves passed through the Tisza from the winter precipitation and thaw waters. The effect of that was still more increased by the influence of flood waves coming from further extraordinary rainfalls between May 11th and 14th and between May 22nd and 24th and later, in the course of June, by the influence of a last considerable flood wave.

In the first third of 1970, in the water system of the Tisza a fundamental hydrological situation came about the water loading of which could only disastrously increased in the months May and June. The climate of the watershed area was controlled, owing to a very strong atmospheric circulation, by regional cyclones. The clash of cold and warm fronts, air bodies of considerably different temperature, ensured favourable conditions for exerting in a short time precipitation of large water output.

Also the mutual effects of the surface formations of the watershed area may be connected close to the flood-inducing atmospheric processes. As a result of the ground relief, there fell sporadically a precipitation amount exceeding 100 mm in the water system of the Upper Tisza, Szamos, Kraszna, Tur, Batár, Lápos and Visó, between May 12th and 14th 1970.

It could be established that in the period May-June 15.5 cubic km precipitation amount fell on the watershed area belonging to the segment of the Tisza at Szeged of which, according to the recordings, 6.9 cubic km flowed through the segment at Szeged. That means that the ratio of flowing through was 44 per cent, considerably higher than the about 20 per cent average value of several years.

In May and June of 1970 an unprecedented flood descended down the Tisza and all its left-hand tributaries. The previously recorded highest flood-levels were exceeded by this inundation by in general at least half a metre, while in the upper reaches of the tributaries the waters rose a metre, and in some places several metres, higher than ever before. The outflow, accumulation and encounters of the large masses of water ridiculed all previous customary "regularities". In certain regions the inundation caused catastrophic damage. The inhabitants of many other settlements were kept in terror. The population of the country, however, urged themselves to heroic resistance, united against the dangers of this natural catastrophe, and spurred themselves on to effective action.

The natural causes which led to the flood situation in the river-system are now accurately known. The primary causes were the extreme hydrometeorological conditions, and also the orographic (i.e. the surface-relief) characteristics of the catchment area. Although the orographic factor is geographically accurately known, a completely reliable forecast can still not be given at present with regard to the occurrence in time and the qualitative and quantitative changes of the hydrometeorological factor. Calculations can be carried out on the basis of our experience, only as regards the frequency, and hence the probability of such occurrences, but the concrete time of their appearance can not be precisely determined.

The series of flood-waves in 1970 (and also the higher floods during the preceding one hundred years too) were generally characterized by the fact that the movement of the rivers of the system and the periods of the flooding differed from those corresponding to average conditions. According to the hydrographic regularities in the river-system, the water-movement of the Tisza is characterized by a possible three flood-waves:

Spring flooding: this results from the melting of the winter's snow or from the spring rains following this, and it takes place along the whole length of the river.

Summer flooding: this is known as the green-flooding, and follows the rains of May and June; it is usually no longer considerable in the Middle—Tisza and in most cases does not even reach the Lower-Tisza.

Autumn flooding: this is a rarer flooding, normally confined to the Upper-Tisza, and is due to the soft rainfalls resulting from the Mediterranean effect.

The simultaneity of the flooding of the tributaries of the Tisza is a fairly rare phenomenon. Although the flood-waves in several tributaries may begin simultaneously as a result of a common reason, due to the difference in their flow-times they are not discharged into the Tisza at the same time, and hence do not usually cause a maximum load there.

This regular water-movement, however, may often be considerably modified, since the precipitation on the water-catchment area is a phenomenon connected primarily with the period and not with a definite season. (Andó 1964) From the point of view of precipitation, the periods of the year can be divided by and large into two characteristic groups:

(i) a shorter, wet period (May-August), and
(ii) a longer, dry period (August-May).

There is no close connection between this time division and the periods when the rivers flood. The early spring flood and the high water-level of the rivers do not result from the amount of precipitation in the spring, but from the melting of the snow which has accumulated during the drier period. If the melting proceeds rapidly and further precipitation falls, the water-supply of the rivers may increase suddenly, and this may give rise to situations of the danger of flooding, either in certain areas or over the entire water-catchment region.

The early summer flood is a result of the precipitation period. In the knowledge of the annual precipitation-distribution of the river-system, the occurrence of flooding at the beginning of the summer can be taken for the most part as certain. At such time, however, the amount of water in the rivers varies considerably as a result, of the occurrence of precipitation and its evaporation. It frequently happens that the average water-supply of the rivers at the time of the early summer floods is less than in the period when the snow melts. Naturally, the extreme situation may also arise, when a considerable water-supply builds up on the catchment area and the rapidly descending waters produce catastrophic floods. This was the case with the flood situation which developed in May and June of 1970. In these months the weather was generally cool for the season, but the weather in the preceding months also differed from the usual.

The snow-cover had already developed on the river-system by the end of December 1969. However, on the action of the sub-tropical, moist air-masses which moved in at the beginning of January 1970 this almost completely melted. The high temperature of the air and the frequent rainfall led to complete melting in the river-system up to a height of about 600 m above sea-level. This melting resulted in the previously essentially frost-free surface soil becoming saturated with the melt-water; thus, the state of affairs had already developed in January that the water-capacity of the soil had been reduced to a minimum. From the middle of February until the first week of March the weather was again cold. The upper layer of soil earlier saturated with water became appreciably frozen, and so its water-permeability too decreased practically to zero. In higher regions relatively thick sheets of ice also formed on certain subsidiary catchment areas, and all this increased and accelerated the surface movement of the later precipitation to a considerable extent.

After the first week of March the rapid exchange and extreme variability of the air-masses produced unsettled weather in the Carpathian basin, and this led to a more rainy state than the average. From the struggle of the polar and the sub-tropical air-masses a more abundant precipitation can mostly be attributed to the sub-tropical air-masses. The spring floods too were caused in almost all cases by the precipitation and melting accompanying a sub-tropical air-mass. With the exception of North-west Transdanubia, the monthly precipitation totals throughout Hungary exceeded the many years' average. In many parts of the country a precipitation surplus of 100—200% developed, and in a considerable area it was even 200—300%. This was accompanied by serious problems regarding the inland waters. In the first half of March the precipitation fell for the most part in the form of snow, but in the second half of the month too snow-storms were observed, and of course heavy rainfalls were not rare either. In the main, air-masses of varying temperature, originating from the seas of the temperate zone, came into prominence, and these acted on the river-system as warm- and cold-fronts. As a result of this relatively rainy situation, together with the melting, the snow-cover of the Carpathian basin was appreciably depleted. By March 20 the melting-limit was already about 1700 m, and it subsequently never fell below 1200 m. At the end of March a (considerable amount, 50—80 mm, of rain fell on the) Upper-Tisza catchment area and caused a considerable mass of the snow-cover to melt. As a consequence of this, the Tisza flood-water at Tokaj on April 2 had already attained 751 cm.

The air-temperature in April was somewhat lower than usual. The monthly amount of precipitation was once more above the many years' average. In the wetter regions the precipitation surplus was again between 100 and 200%. Stormy weather too was frequent. Hail fell on the Great Hungarian Plain, and snow on the hilly districts. The catchment area came in turn under the effects of moderate air-masses and others originating from the Arctic Ocean. The effects of the many cold-fronts and the related cooling too increased the surface water-supply, since the extent of evaporation was lower than usual. The April temperature remained 0.4—0.5 °C below the average, and in May this difference became 2 °C even. These values alone indicate that cold air-masses predominated in the Carpathian basin.

During the first four months of 1970 in the Tisza river-system a hydrological situation arose, the water-load of which was increased to catastrophic proportions in May and June; these months normally belong among the rainier ones, anyway, but for the most part they turned out to be extremely wet. The precipitation which had fallen in the winter and spring had practically completely saturated the soil. At the same time, the snow still remaining was undergoing rapid melting. Because of the

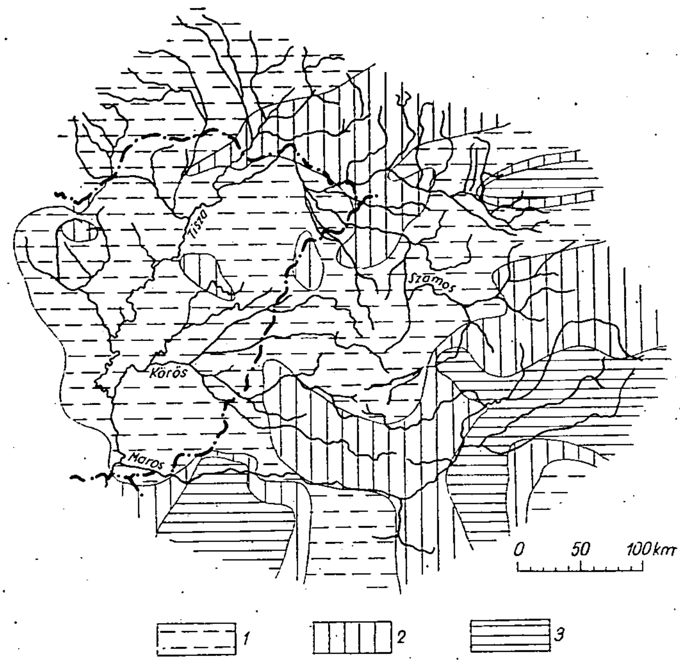

Fig. 1. Precipitation distribution, May 1—5, 1970 (pentad I).

extremely high moisture content of the air, evaporation was severely restricted, and indeed the evaporated water at best merely increased the cloud-formation. The beds of the water-courses were filled with the winter-spring ice-waters and they were restricted in their outflow. In this state, five very serious flood-waves descended down the Tisza up to the end of April, and as a result the May outflows were greeted by full beds. And, after all this, in May the precipitation was even higher than before.

As a consequence of the very strong atmospheric circulation, the weather of the catchment area in May was determined by regional cyclones. Cold- and warm-fronts, and the encounter of air-masses of very different temperatures, produced a condition favourable for the occurrence of a considerable precipitation in a short time.

The regional formation of precipitation in the river-system during May 1970 can be assessed on the basis of the effects of three types of air-mass:

1. Moderately cool air-masses originating from seas of the temperate zone gave rise to frontal rains following each other from the N. W.
2. Cold air-masses of polar origin, with strong turbulence, discharged locally extensive precipitations onto certain parts of the catchment area.

3. Warm air-masses (sub-tropical fronts) with centres of low air-pressure provided regionally-varying amounts of precipitation.

The atmospheric events in May, which resulted in catastrophic consequences, may be divided into pentads to give the following picture:

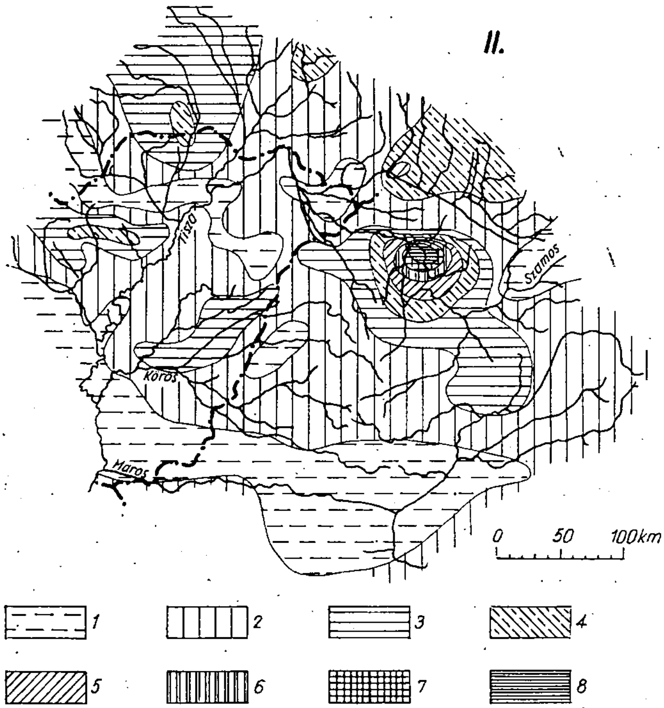

Fig. 2. Precipitation distribution, May 6—10, 1970 (pentad II).

Pentad I, May 1—5:

Precipitation was produced in the river-system by a complex front, and then a cold air-wave. Snow fell again in the hilly districts. The snow-cover was 20 cm at a height of 800 m above sea-level, and 100 cm above 2000 m. Relatively rainy and cool weather dominated over the catchment area, similar to that in Western Europe, but in contrast Eastern Europa experienced tropical heat, the temperature in Moscow reaching +27 °C (Fig. 1).

Pentad II, May 6—10:

Warm air from Eastern Europe streamed towards the Tisza catchment area as a result of the tropical air-masses, and so melting began everywhere. The maximum value of the air-temperature was 8—10 °C higher than the many years' average. Thus, in the mountainous areas of Rumania melting even continued at night. Variable precipitation and regional storms were produced in the catchment area. The catchment areas of the Upper Tisza, the Szamos and the Kraszna received a considerable precipitation of some 70—80 mm. In a period of only 10 days, therefore, a precipitation approximately equivalent to the many years' average for the whole month fell on this north-eastern regional catchment area (Fig. 2).

Pentad III, May 11—15:

At 6 p.m. on May 11, with the break-through of a cold-front, a polar air-mass advanced towards the catchment area. A deep cyclone system developed over the northern part of the catchment area, with an air-pressure below 740 mm Hg. With this advection two moist air-masses met above the river-system. The very high water vapour content of the air (12—20 g/m^3) resulted in an abundant precipitation. The movement of the cyclone was restricted by the North-Eastern and Eastern Carpathians, the air-mass was forced to ascend, and this led to a strong increase of the cloud-formation (cloud-level 7,500 m) and of the precipitation-intensity. With the retarding action of the relief, on May 12—13 a new, polar, cold air-mass caught up with the cyclone slowly moving in the north-east of the catchment area, and as a result a 100—120 mm precipitation fell within a short space of time. (In Beszterce-Naszód, Máramaros and Maros counties, almost 2.5 km^3 of water fell on about 50,000 km^2 in 72 hours.) During the 48 hours from 8 a.m. on May 11 to 8 a.m. on May 13, 72 mm of rain fell on Nagybánya, 99 mm on Beszterce, and 105 mm on Maroshévíz. Measurements and estimations suggested (that even 150 mm may have fallen locally.) It may be presumed that if the range of the Carpathians had not been there, such an extensive precipitation would not have occurred. For instance, the 70—80 km-wide

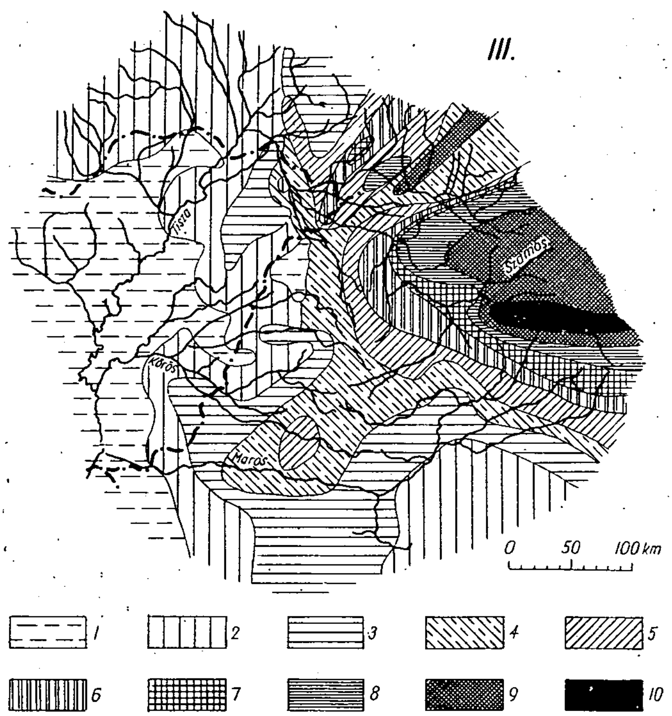

Fig. 3. Precipitation distribution, May 11—15, 1970 (pentad III).

1. 0—10 mm
2. 10—20 mm
3. 20—30 mm
4. 30—40 mm
5. 40—50 mm
6. 50—60 mm
7. 60—70 mm
8. 70—80 mm
9. 80—90 mm
10. 90— mm

front, moving at some 40 km/hour, resulted in only2 hours' rain-showers and hail on the Great Hungarian Plain. At the same time, on the upper catchment areas of the Szamos and the Maros the slackening and rising cold-front collided with the sub-tropical air-pocket stagnating there, and as is well known this led to the catastrophic rainfalls (Fig. 3).

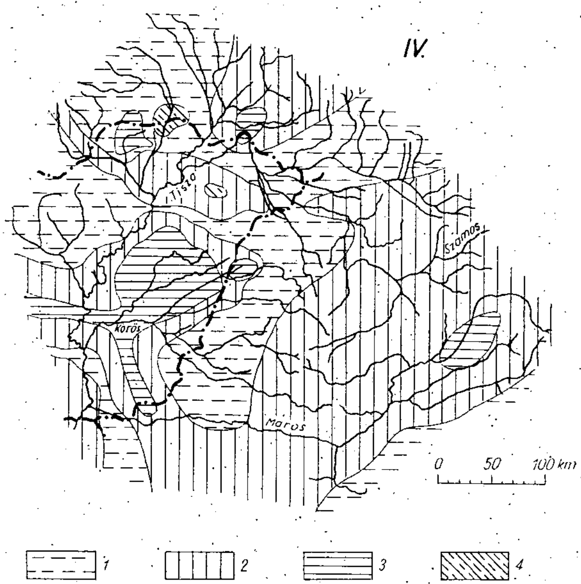

Fig. 4. Precipitation distribution, May 16—20, 1970 (pentad IV).

Pentad IV, May 16—20:

Following this large inundation, a relatively quieter period developed as regards precipitation, although the atmospheric instability was fairly considerable. In the first part of the pentad, even cooler and rainier air-masses were predominant, whereas in the second part warm, dry air-masses took over (Fig. 4).

Pentad V, May 21—25:

This period, beginning with a rise in temperature and local downpours, led mainly in the Maros valley to surface outflow which together with the melt-waters produced a new, considerable flood-wave. A 20—60 mm precipitation fell on the S.E. parts of the river-system on May 23 and 24. In the period June 1—3 the water flowing down the Maros, which had fallen in pentad V, met the mass of the N.E. waters which had fallen in pentad III, and this gave rise to the highest water-level of 961 cm at Szeged (Fig. 5).

Pentad VI, May 26—31:

The weather was relatively clear, although a few more significant downpours did further increase the already considerable flood-waves of the catchment area (Fig. 6).

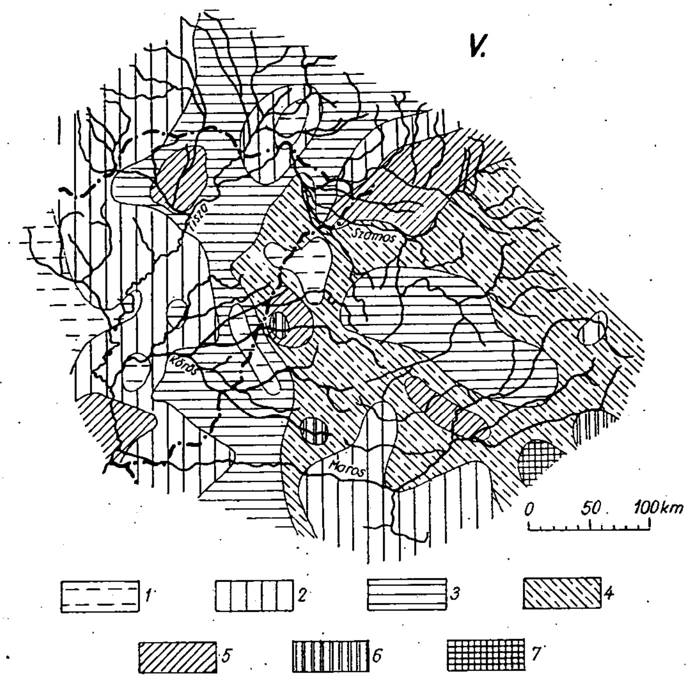

Fig. 5. Precipitation distribution, May 21—25, 1970 (pentad V).

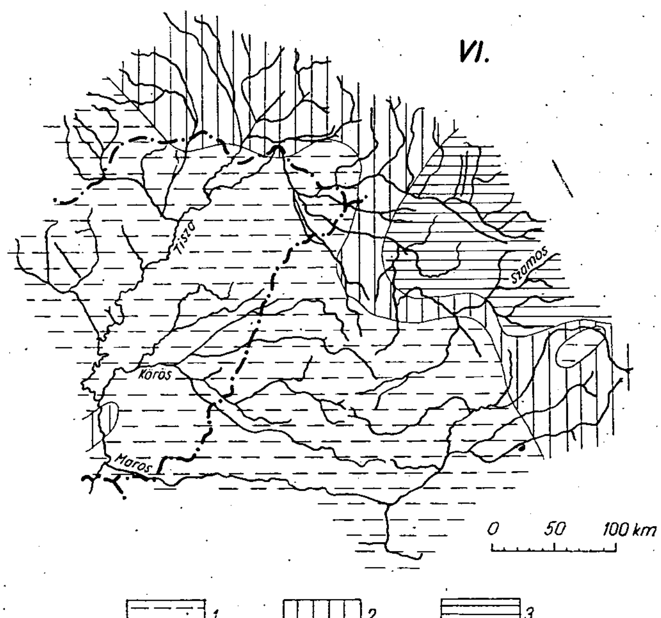

Fig. 6. Precipitation distribution, May 26—31, 1970 (pentad VI).

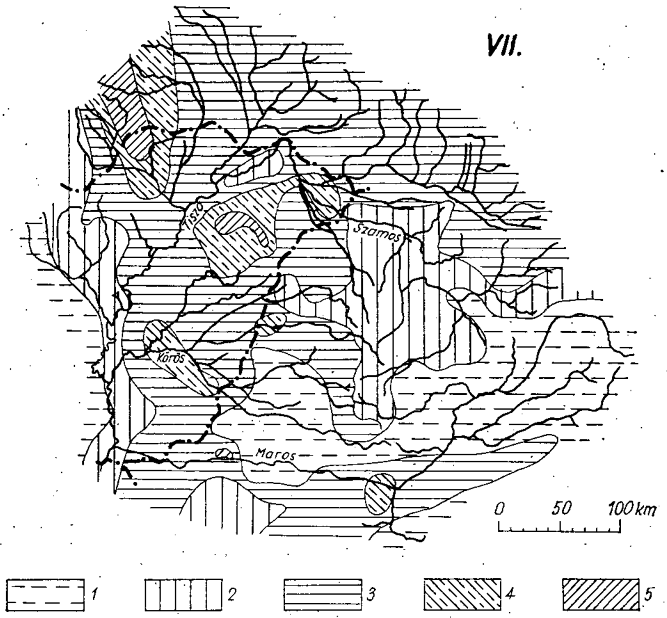

Fig. 7. Precipitation distribution, June 1—5, 1970 (pentad VII).

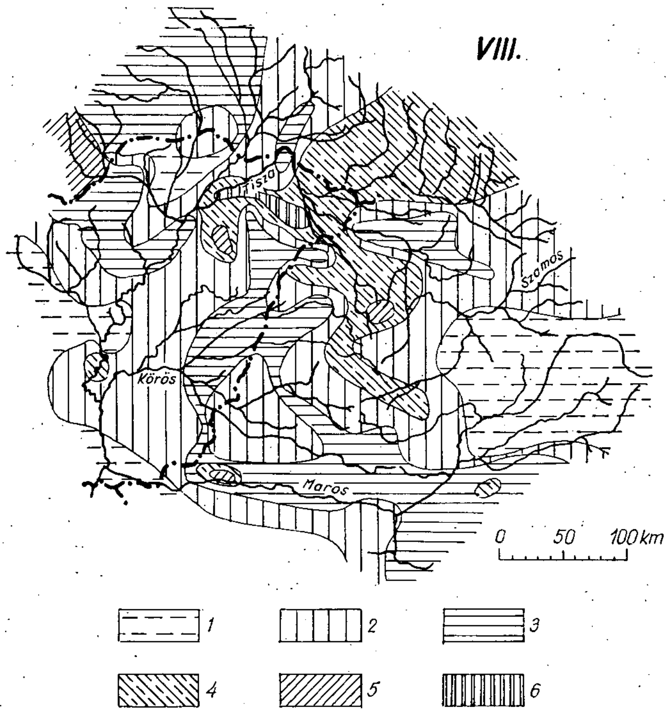

Fig. 8. Precipitation distribution, June 6—10, 1970 (pentad VIII).

Pentad VII, June 1—5:

The cold-front effects still held, and the daily average temperatures were relatively low for the season. Although the precipitation activity was in the form of scattered showers and thunder-storms, never-theless it further increased disquietingly. A cyclone moving in from the N.E. settled on the river-system (Fig. 7).

Pentad VIII, June 6—10:

The catchment area again came under an unstable atmospheric effect. The succession of sub-tropical, arctic and Atlantic air-masses produced variable weather and caused locally high precipitation, violent downpours and storms (in places hail) on the catchment area (mainly on that of the Körös rivers Fig. 8).

Pentad IX, June 11—15:

The humid air-mass in the first part of the pentad, together with a very high temperature, was a favourable condition for the local formation of thunder-storms. This state was disturbed in the second part of the pentad by cold air with a strong wind from Scandinavia, and this gave rise to a cold-warm air mixed zone above the Ukraine and the eastern part of the catchment area. It is characteristic that with the very changeable temperatures the amount of precipitation also developed in an extreme way. Such a large amount of precipitation fell during this time, primarily on the Körös catchment area, that the flood-wave there exceeded all previous levels, while on the Maros and the N.E. waters the state of danger produced in pentad III in May seemed to be repeated (Fig. 9).

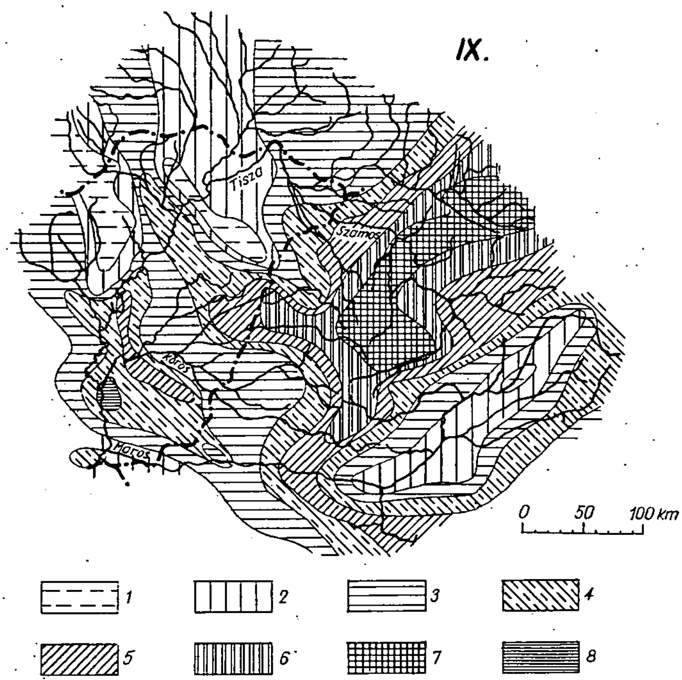

Fig. 9. Precipitation distribution, June 11—15, 1970 (pentad IX).

As has been seen already, the direct causes of the precipitation were known, but these may not provide a completely satisfactory explanation. The main cause of the period of haphazard but heavy precipitation in the first half of 1970 can be deduced from the climatic situation which developed in the northern hemisphere. While it was extremely cold in N. Europe, at the same time it was an exteremely warm winter in N. Africa. The two air-masses of such different temperatures gave rise to an extremely active mixed zone between the 40th and 50th parallels. The tropical air-masses often penetrated even to the Baltic. The struggle between the cold and warm air was repeated almost daily in the temperate zone, and polar and tropical days alternated with high frequency. Although it is not a common phenomenon that the polar air-mass comes into direct contact with a tropical air-mass (it usually transforms to an intermediate sub-polar and a sub-tropical air-mass), this now occurred above Europe, and completely changed the normal circulation.

The interactions of the surface-forms of the catchment area can also be closely related with the above-listed atmospheric processes giving rise to the flood.

As is well known, the atmospheric advections extending to the whole of the basin did not in general exhibit uniform precipitation distribution. In the main, heavy and rapid precipitation activities were confined only to smaller areas. One of the reasons for this is to be found in the surface-relief. Thus, the situation, form and height of the hills, the steepness of their slopes, the flora covering the surface, etc., are always the most important factors of the orographic precipitation formation. For example, on the occurrence of N.W., W. or S. W. winds, those ridges of the Máramaros snow-capped mountains which extend in the N-S direction act as „precipitation traps". The situation is similar to this with the northern slope-exposure of the Sziget mountains in Transylvania. The heaviest rainfalls generally occur here when the centre of the accompanying air-pressure minima and the intensified Atlantic cyclone activity is situated over the Polish Plain and the Ukraine. At such time the rapid increase of the air-flow on the exposed side of the mountain may give rise to intense precipitation. In addition to these areas, similar orographic conditions occur in many other places too in the river-system. In such cases the surface size and height of the relief may play an important role in the formation of local and heavy precipitation. The "memorable" rains which fell in the period May 12—14, 1970 are also closely connected with the orographic conditions. As a result of the relief (exposure, upwards flow on the slope, etc.), in places more than 100 mm precipitation fell on the river-system of the Upper Tisza, the Batár, the Túr, the Szamos, the Kraszna, the Lápos and the Viső.

Table 1. *Annual total (mm) of the precipitation increase for a rise of 100 m, calculated on the basis of the 40 years' average*

Western slope of the Bihar range	45 mm
Western slope of the Avas range	71 mm
Western slope of the Kőhát range	42 mm
Western slope of the Lápos range	33 mm
Western slope of the Bükk range	50 mm
Western slope of the Radnai snow-capped mountains	33 mm
Western slope of the Kelemen snow-capped mountains	50 mm
Western slope of the foothills of the Southern Carpathians (Bánáti range)	100 mm

The amount of precipitation varies in the mountains with the increase of the relief above sea-level. The values calculated on the basis of the average annual precipitation (40 years' average) on exposed western slopes of the individual mountainous districts of the river-system show that certain mountains are in a favourable geographical position in the paths of the air-currents delivering the precipitation (Table 1).

The surface water-course density too may be taken into consideration as a factor producing the flood-state.

According to the water-course densities, the catchment area of the Tisza is asymmetrical. Primarily the left-hand tributaries have a large effect on the supplementing of the Tisza water-supply, and on the conditions for the development of flood-states. It may be stated as a fact that the relief of the left-side river-system, the density of the river-network, and the regional precipitation distribution are the main factors controlling the flow of the Tisza (Fig. 10).

Fig. 10. Surface relief of the river-system.
I. N. E. catchment area of the Tisza (Upper Tisza, Szamos, Kraszna, Túr, Batár, etc.)
II. Cachtment area of the Körös rivers
III. Catchment area of the Maros
IV. Other, right-bank Tisza catchment areas (Bodrog, Sajó, Zagyva, etc.)

In general, the tributaries of the Tisza can be divided into two groups on the basis of the surface-relief. The first group comprises those rivers which possess considerable mountainous district catchment areas, arrive via very rainy valley-sections to the Tisza basin on the Great Hungarian Plain, and here, after a relatively short section on the Plain, reach their erosion-basin, the Tisza. The courses of these tributaries are typified by their torrent nature. The water-supplies of the rivers may be characterized as a function of the development with time of the prevailing amount of precipitation. The following tributaries can be classified in this type: the Beszterce, the Szamos, the Almás, the Lápos, the Túr, the Kraszna, the Sebes Körös and the Fekete Körös. The other group contains those tributaries which, after their mountain origin, thread down with numerous mountain-basins. They reach the region of the Great Plain via valley-sections where comparatively less rain falls. Their courses are generally not typified by a torrent nature, but that does hold here too in certain valley-sections. The water-supplies of the rivers are obtained from the soil-water too, in addition to the precipitation factors, by means of the tapping of alluvial and detrital cones. In such types of rivers, flood-wave courses protracted in both time and extent are possible. The primary example here is the Maros, although the first May flood-wave in 1970 had a similar torrent-type nature.

The natures of the surface-formations, the surface-relief and the precipitation factors can all exert a significant influence on the density of the river water-network, which again and again is an important factor in the regional development, of the flood (MORARIN and SAVU 1954). The density of the river-network is the greatest in the region of the Radnai and Máramarosi snow-capped mountains, the volcanic range of the Avas, the Gutin and the Cibles, the Borgói, Kelemen, Gyergyói, Csíki Görgényi and Baróti snow-capped mountains, the Fogarasi, Almási and Ruszka snow-capped mountains, and the Southern Carpathians, and, from the Transylvanian Sziget mountains, on the regions of the Bihar, the Gyulai, the Királyerdő and the Érchegység mountains. (The water-network is particularly dense on the left-hand catchment area of the Fekete Körös, where at times it even exceeds 1.0 km/km^2.)

A medium density of 0.3—0.6 km/km^2 can be observed on the table-land of the Szamos, in the Transylvanian basin, on the regions of the Mezőség and Szilágyság, and also on the alluvial cones of the rivers coming out of the mountains. The surface water-network is very rare (0.06—0.03 km/km^2) in the Great Hungarian Plain.

The density value of the water-network assumes a characteristic picture in the catchment areas. Thus, for example, the western part of the Transylvanian Sziget mountains and the N. E. Carpathians can be assigned as one such belt, which comprises the catchment areas of the Upper Tisza, the Visó, the Iza, the Batár, the Túr, the Szamos, the Sebes Körös and the Fekete Körös. The relief of the ground here is of favourable exposure for the air current bringing the precipitation, and a "luw" zone develops, where the torrential possibilities of the course of the river are considerable.

The other zone is on the catchment region of the Kis Szamos, the Nagy Szamos, the Fehér Körös, the Maros, the Aranyos and the Küküllők. The density of the surface water-network here is 0.5—0.6 km/km^2, and the precipitation conditions of the catchment area are more moderate than the above.

The density of the surface water-network is influenced to a large extent by the variable stone composition of the surface, the individual tectonic structures, the extents of the drought factors and the precipitation, the form of the water catchment area, its spatial situation, the degrees of soil and plant cover, and not least by the activity of society in reshaping nature (Fig. 11).

The amounts of rain-water which fell in May and June, 1970 are summarized in Table 2. The Table indicates quite sharply the individual periods and partial catchment areas in which more concentrated amounts of water were set in motion. On the partial catchment areas of the north-east tributaries of the Tisza (the catchment areas of the Upper Tisza, the Szamos, the Kraszna, the Túr and the Batár, completely up to the Vásárosnamény section of the Tisza), after preparatory rains of gradually increasing amounts the outstanding value of 1.6 km^3 arose in pentad III. On the other hand, the amounts of water in pentad V, and particularly pentad IX, were also considerable. In May and at the beginning of June, the water-load on the catchment area of the Körös was almost uniform, but relatively quite high. Clearly,

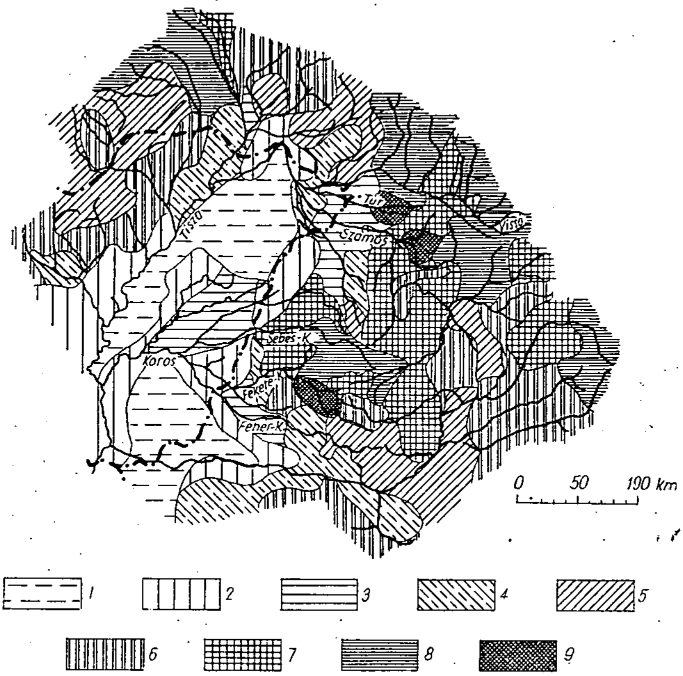

Fig. 11. Water-course density in the river-system of the Tisza.

1. 0.0—0.1 km/km$_2$
2. 0.1—0.2 km/km$_2$
3. 0.2—0.3 km/km$_2$
4. 0.3—0.4 km/km$_2$
5. 0.4—0.5 km/km$_2$
6. 0.5—0.6 km/km$_2$
7. 0.6—0.7 km/km$_2$
8. 0.7—0.8 km/km$_2$
9. 0.8—0.9 km/km$_2$

this could be increased only to a catastrophic level by the further extreme amounts of water in pentad IX, if it is considered that the consequences of the previous water-load had still not disappeared during the short time available. The load of the catchment area of the Maros was in general evened out, more so than the loads of the Upper Tisza and the Szamos, but during the whole period of the flood it was very intense. The waters of pentads III and V initiated the two large flood-waves on the Maros. The waters of pentads VII and VIII, and especially of pentad IX, ensured the relatively more uniform, but overall extremely heavy water-load of the Maros in June, and this determined the lastingness of the June flood-wave at Szeged, and, together with the accumulating waters of the Körös rivers, the prolonged height of the Tisza too (Table 2).

Table 3 shows the average precipitation totals which fell in the individual pentads, from a knowledge of the partial catchment areas (the N.E. waters meeting up

Table 2. *1970. precipitation (in km³)*

Pentad		N. E. waters	Körös	Maros	Other	Total
May	1— 5	0.1	0.1	0.3	0.2	0.7
	6—10	0.6	0.3	0.2	0.6	1.7
	11—15	1.6	0.3	0.9	0.2	3.0
	16—20	0.2	0.3	0.3	0.2	1.0
	21—25	0.8	0.3	0.8	0.3	2.2
	26—31	0.4	0.1	0.2	0.2	0.9
June	1— 5	0.5	0.4	0.4	0.4	1.7
	6—10	0.3	0.3	0.5	0.3	1.4
	11—15	0.9	0.7	0.9	0.4	2.9
Total		5.4	2.8	4.5	2.8	15.5

Note: N. E. waters = waters uniting up to the Vásárosnamény section of the Tisza (Tisza, Szamos, Kraszna, Túr, Batár, etc.).

to the Vásárosnamény section: 32,000 km²; the Körös rivers: 26,600 km²; the Maros: 29,800 km²; and other Tisza tributaries together: 50,000 km²; in all up to the Szeged section, i.e. to the Yugoslav frontier: 138,400 km²). These data are also suitable for comparison, although the outstanding values may scarcely be demonstrated (Table 3).

The next questions is what proportion of the waters resulting from the precipitation made its way down the rivers. In the determination of this the rate of flow and the mass of the water in the Szeged section of the Tisza must be taken into account. During the flood-defence work (starting from May 27), the rates of flow of the water were measured directly (by the measurement of the flow-rate at many points of the bed-section, and by the multiplication of the rates by the reference surfaces, and then the summation of the partial flow-rates NÉMETH 1954). The other flow-rates (between May 19 and 26) could be determined by calculation from a consideration of the measured and calculated flow-rates at places outside Szeged. The flow-rates of the period preceding the flood were obtained, in the knowledge of the water-levels which were systematically read off daily, from the so-called „flow-rate (curve", which expresses the flow-rates) as a function of the water-level. It should be noted that the flow-rate curve would not have been usable in the May-June periods of the flood, since it would not have been possible to apply it to the high water-levels which

Table 3. *1970 average precipitations (in mm)*

Pentad		N. E. waters	Körös	Maros	Other	Overall average
May	1— 5	3.1	3.7	10.0	4.0	5.1
	6—10	18.8	11.2	6.7	12.1	12.3
	11—15	50.0	11.2	30.0	4.0	21.6
	16—20	6.3	11.2	10.0	4.0	7.3
	21—25	25.0	11.2	26.7	6.1	16.0
	26—31	12.5	3.7	6.7	4.0	6.5
June	1— 5	15.6	15.0	13.4	8.1	12.3
	6—10	9.4	11.2	16.7	6.1	10.1
	11—15	28.2	26.2	30.0	8.1	21.0
Total		168.9	104.6	150.2	56.5	112.2

Note: N. E. waters = waters uniting up to the Vásárosnamény section of the Tisza (Tisza, Szamos, Kraszna, Túr, Batár, etc.).

occurred, while in addition, because of the various water-accumulation effects, the relation between the flow-rate and the water-level was not clear-cut during the flood. The actual relation resulted in a spe-cially involved variation of the flood loop-curve (Fig. 12).

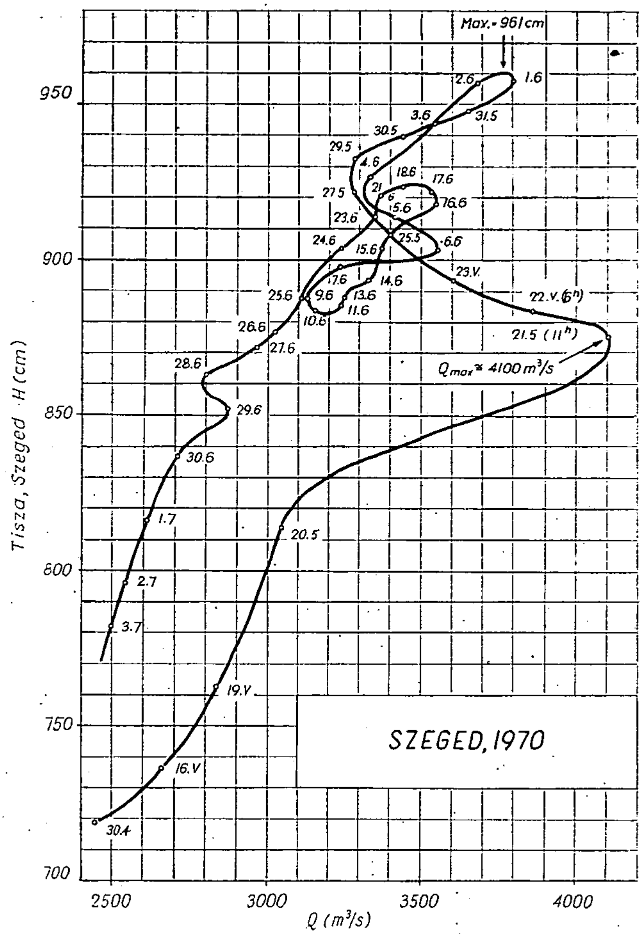

Fig. 12. Relation between the water-level and the flow-rate at Szeged in 1970. (Flood loop-curve)

The series of times of the flow-rates for the Szeged section (Fig. 13), however, does not always show the desired amount of the outflow, since the water would also have flowed in the Tisza (but much less) if by chance it had not rained in May and June. Thus we had to distinguish the outflow waters of the period before May 1 from those of the following period, in the series of times of the flow-rates. This was done by extending in an arc the receding branches of the April flood-wave of the Tisza completely to the beginning of the July flood-wave following the great flood, in accordance with the 4—6 weeks more advanced receding tendency observed on the upper water-gauges compared with that at Szeged (Fig. 13). The Tisza at Szeged during the summer otherwise maintained a flow-rate of 900—1,000 m³/s. Since that flood-wave which passed Szeged on April 23 reached its maximum at Tokaj on April 2, and at Vásárosnamény on March 30, it was possible to determine relatively accurately the subsiding tendency of the April flood-wave assumed for Szeged (Fig. 13).

The area measurable between the receding line of the waters originating before May 1 and the flow-rate — time line of the waters which actually flowed (the time data are in sec) gives the amount of the waters originating after May 1. This was found to be 6.9 km³. If this is compared with the amount of precipitation, 15.5 km³, it can be seen that 44% of the latter had flowed past Szeged up to July 18, 1970. This outflow fraction was substantially higher than the many years' fraction, ca. 18—20%, for the whole of the catchment area region, and confirmed the strong limitations on the infiltration and evaporation, especially during May.

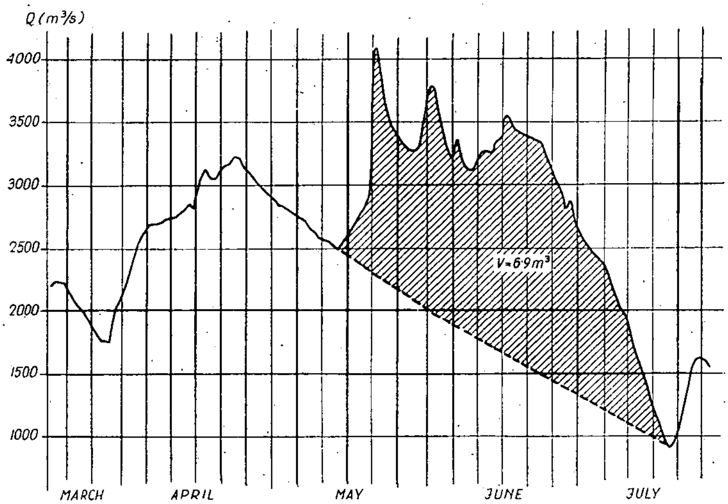

Fig. 13. Series of times of flow-rates, and flow-rates and amounts of precipitation after May 1 at Szeged.

In addition, we also determined the changes with time of the amounts of the outflow waters for the Szeged section and the precipitation amounts there, and thus the change with time of the outflow fraction (Fig. 14). The times of the fall of the precipitation had to be converted for the Szeged section. The actual outflow rates of the flood-water and the extension in time of the moving flood-waves were taken into consideration, and the relevant amounts of water during this were found for those days on which these should have in theory passed the Szeged section (without infiltration and evaporation losses). In the knowledge of the actual amount of water which flowed past on that day, the outflow fraction too could be determined. The water amounts mentioned were expressed by their values amassed (integrated) from May 1 (Fig. 14).

Thus, it can be seen that the observed movements of the flood-waves in the Tisza river-system in 1970 not only developed in a complex way, but, as a result of the extreme amounts of water and the congesting effects of the individual tributaries on each other, also severely tried the technical structures and technical strengths of the Hungarian flood-defence.

The Tisza and its tributaries were confined between embankments in the last decades of the 19th century, on the basis of the ideas and plans of ISTVÁN SZÉCHÉNYI and PÁL VÁSÁRHELYI, which had been developed in the first half of that century. Since their construction these embankments had been reinforced many times. Hence, about a quarter of the territory of Hungary had been freed from the periodically recurring overflows of the flooding rivers. The development of modern industry, agriculture, the traffic system, and even human settlements would not have been

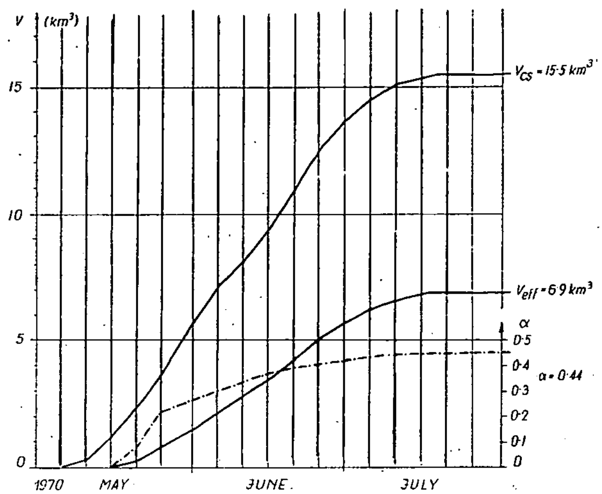

Fig. 14. Precipitation and outflow values reduced to Szeged.
Vcs = summed water content of the precipitation
Veff = amount of water due to precipitation passing Szeged after May 1

$$\alpha = \frac{\text{Veff}}{\text{Vcs}} = \text{outflow fraction for Szeged}$$

possible on a large part of Hungary without the removal of the threat of flooding in the Tisza valley (BOGDÁNFY 1904). However, the embankments raised the levels of the previous highest floods, and are still raising them today. This is particularly the case for the lowest-lying Lower Tisza region (downstream from the mouth of the Körös), and Szeged is most characteristic for this (see Table 4). The flood-waves of the tributaries can pile up on each other here, and even the high water-levels of the Danube can exhibit their effects here. The regulation of the Körös and the Maros, on the other hand, greatly accelerated their flows. By this means it could be attained that the first wave of the flood-waters flows out of the Lower Tisza sooner, and before the peak of the flood-wave of the Upper Tisza reaches this section. However, it did not prove possible by means of flood-defence and river-regulation to prevent the situation when the later, renewed flood-waves of the tributaries mentioned meet, although rarely, with the flood-waves passing down the Tisza (IVÁNYI 1948). (Table 4).

In 1970 two large flood-waves set out from the waters of the N. E. tributaries of the Tisza: the first attained its maximum level of 912 cm at Vásárosnamény on May 15, 12 cm higher than the previous maximum, while the second reached 830 cm on June 14. Two flood-waves set out on the Körös in June. The first of these was still

Table 4. *Annual maximum water-levels of the Tisza observed on the Szeged water-gauge, in descending order of magnitude (1892—1970). (Based on the compilation of* Dr. I. Zsuffa*)*

Serial number	Water-level (cm)	Date	Serial number	Water-level (cm)	Date
1	961	2 Jun 1970	41	626	4 Mar 1969
2	923	15 Apr 1932	42	614	2 Apr 1917
3	916	12 May 1919	43	604	19 Apr 1898
4	884	12 Apr 1895	44	604	4 Jun 1957
5	870	11 Apr 1924	45	603	20 Mar 1931
6	855	12 May 1941	46	602	31 Mar 1947
7	847	11 Apr 1940	47	599	15 Apr 1968
8	820	22 Apr 1962	48	595	16 May 1908
9	802	20 Jul 1913	49	594	6 May 1935
10	799	5 Mar 1966	50	587	29 Mar 1963
11	791	31 Dec 1915	51	582	27 Feb 1960
12	791	1 Jan 1916	52	579	1 Jun 1939
13	790	26 Mar 1967	53	568	27 Jun 1894
14	780	7 Mar 1942	54	563	13 Apr 1911
15	778	3 Apr 1914	55	555	4 Apr 1945
16	774	8 Apr 1922	56	552	7 Apr 1896
17	764	17 Apr 1964	57	550	14 Jun 1906
18	759	12 Jan 1926	58	550	23 May 1951
19	758	24 Apr 1907	59	542	23 Apr 1928
20	753	4 Oct 1912	60	526	24 Mar 1934
21	748	22 Jul 1965	61	525	23 Feb 1900
22	730	17 Apr 1897			23 May 1900
23	730	7 Mar 1958	62	525	11 Apr 1946
24	726	17 Jun 1893	63	522	24 Dec 1950
25	714	29 Jan 1948	64	511	28 Apr 1905
26	708	26 Jan 1920	65	508	16 Júl 1903
27	706	17 Jan 1953	66	496	12 May 1910
28	703	2 Apr 1937	67	496	29 Nov 1930
29	689	7 May 1956	68	495	30 Jul 1949
30	681	31 Dec 1925	69	488	18 Mar 1927
31	680	28 Mar 1901	70	472	14 Apr 1936
32	668	1 Jul 1902	71	460	5 Jun 1899
33	660	17 Jul 1933	72	458	9 May 1929
34	657	3 Mar 1955	73	454	13 Mar 1954
35	654	2 May 1944	74	450	18 Feb 1904
36	648	23 Apr 1952	75	436	30 Jan 1959
37	642	7 Apr 1909	76	394	1 Jan 1961
38	638	16 May 1938	77	366	7 Apr 1943
39	637	19 Mar 1923	78	349	31 Dec 1918
40	630	12 Apr 1892	79	325	29 Apr 1921

only partial; it caused higher-water-levels on the Fehér Körös, only filled out the Hármas Körös rather, and could no longer be distinctly detected in the Tisza. The second Körös flood-wave, however, attained a new peak at Gyoma on June 14 of 918 cm (45 cm above the previous record), and its effect at Szeged (together with the flood-waves of the Maros) could be observed on June 18 during the second maximum of 924 cm. This was 1 cm more than the previous record water-level of 923 cm at

Szeged in 1932. On the Maros, two larger flood-waves set out in May and two more in June (practically). The first Maros flood-wave set a record of 928 cm at Gyulafehérvár on May 15 (the previous highest water-level there was 561 cm)!. At 10 p.m. on May 20 this Maros attained a level of 624 cm at Makó (the previous highest water-level there was 580 cm!). The effect of the Maros flood-wave was felt at Szeged in the evening of May 21. The record flow-rate of 4,000 m^3/s was observed. The second Maros flood-wave reached its maximum at Gyulafehérvár in the morning ofs-May 25 (550 cm). This caused a peak-level of 544 cm at Makó between 6 p.m. on May 31 and 8 a.m. on June 1, while at Szeged it was this flood-wave which, combining with the peak-waters arriving from the Upper Tisza, gave rise to a period (between 2 p.m. on June 1 and 4 a.m. on June 2) when the water-level was in general 960 cm, attaining its maximum of 961 cm at 1 a.m. on June 2. Since the first Tisza flood-wave itself would have arrived at Szeged on June 3, the peak of the second Maros flood-wave avoided a precise meeting with it, preceding it by only one day, but naturally even so the two flood-waves strongly enhanced each other's effect. The first great flood-wave meeting at Szeged therefore occurred during the 1970 flood, between the Tisza flood-wave which originated in the north-east in pentad III and the second Maros flood-wave of pentad V. The second flood-wave meeting, which produced water-levels not much lower than those of the first meeting and in excess of the previous record levels, took place in the period June 17—19; at this time the almost confluent third and fourth flood-waves of the Maros in the Makó section resulted in a prolonged peak-level period, and at the same time the effect of the large flood-wave of the Körös in pentad IX made itself felt in the water-level of the Tisza at Szeged. (The peak-level at Szeged was 924 cm on June 18.) The second Tisza flood-wave did not meet with this, all the more so because it originated with the third Körös and the fourth Maros flood-waves (Fig. 15., 16).

The meetings of the flood-waves are also illustrated graphically (Fig. 17). The diagrams include the most important tributaries, the days on which the peaks were reached, and the descent times. The meetings of the flood-waves of the tributaries and the main river can be well followed from the identity or the closeness of the peak-level dates (BUSACKER SAALY 1969). (Fig. 17).

When the outflow durations of the 1970 flood-waves are taken as basis (although these durations are far from constant, and indeed because of the water-retention of the wave-areas with the increase of the amount of the outflow water are never reduced more considerably), it can be established that if the flood-wave setting out in the N.E. tributaries of the Tisza is followed 10—12 days later by a flood-wave on the Maros, and 13—17 days later by one on the Körös, and if the amount of water in these flood-waves is extreme, then we are faced with the most dangerous state of build-up the waters as regards not only Szeged, but also the whole Lower Tisza region too.

Naturally the defence-works of Szeged and the Tisza are able, perhaps with difficulty, but with appropriate defence preparedness and efforts to cope with waters 1—1.5 m higher even than those of 1970. It is also true, however, that the water-levels in 1970 are not the highest which may conceivably happen, in spite of the fact that as regards the meetings the most dangerous state of rainfall on the Tisza, the Maros and the Körös at suitably delayed times, together with extreme flow-rates and water-levels, has never before occurred with complete precision. The averting of the flooding of the Tisza and its river-system was a great historic act, but as a result of our natural endowments there will always be periods when the flood-defence will again call for heroic deeds to protect the country and the people.

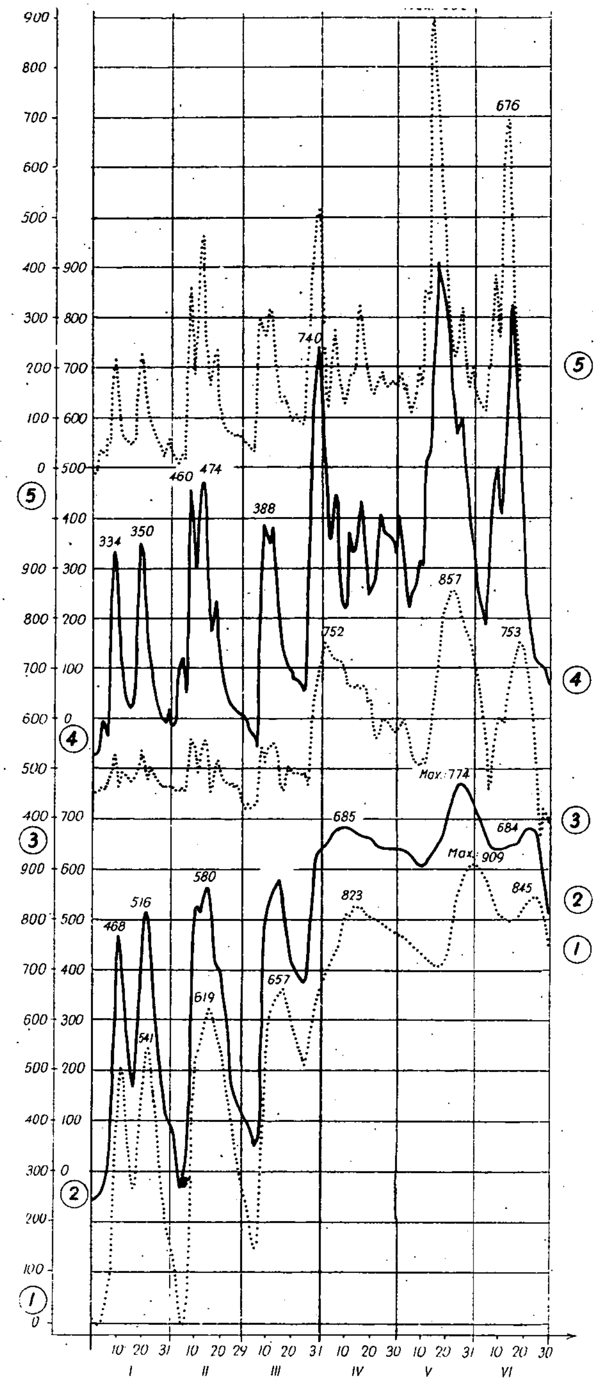

Fig. 15. Series of times of water-levels on the Tisza and its tributaries in the first half of 1970. LNV = highest water. *1.* Szolnok, *2.* Tiszafüred, *3.* Tokaj, *4.* Vásárosnamény, *5.* Csenger

If a study is made of which are the most dangerous periods with regard to the development of the extreme floods of the Tisza, we can primarily again point only to the remarkable differences from the regularities of the Tisza and its river-system which can be observed during the larger floods. From the times of the peak water-levels observed in the individual years (Table 4), it is not possible to make clear-cut conclusions as to a function between the maximum water-level and the season. The monthly distribution of the maximum yearly levels of the Tisza on the Szeged water-gauge for

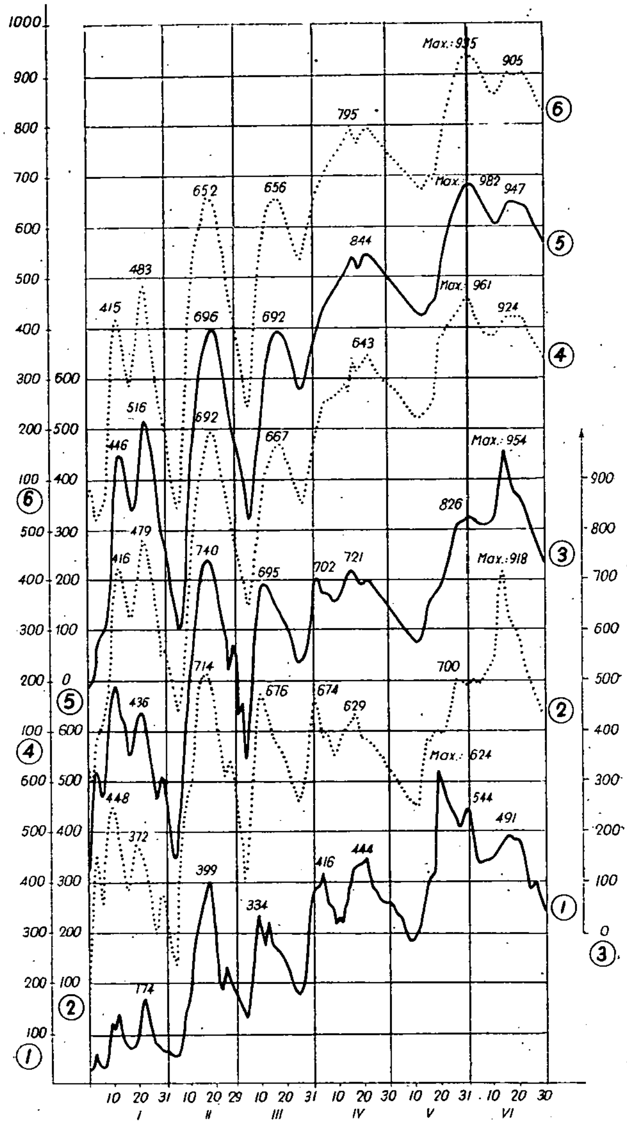

Fig. 16. Series of times of water-levels on the Tisza and its tributaries in the first half of 1970. LNV = highest water.
1. Makó, *2.* Gyoma, *3.* Szarvas, *4.* Szeged, *5.* Mindszent, *6.* Csongrád

the last 80 years is as follows: in January: 7 times; in February: 3 times; in March: 14 times; in April: 26 times; in May: 11 times; in June: 7 times; in July: 6 times; in October: once; in November: once; and in December: 4 times. If the highest annual maxima are taken, however, it emerges that the majority of these were in April, and to a lesser extent in March, while all the levels above 850 cm occurred between May 2 and June 1. Since 450—700 cm maxima also occurred frequently in these

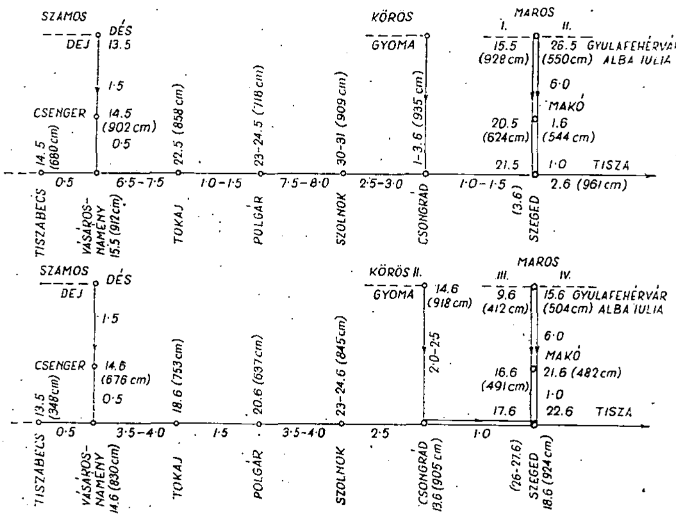

Fig. 17. Graphical diagram of the Tisza valley flood-wave descent in May and June. (The dates are the days of the peak levels; the cm values in bracketsar e the maximum water-levels; and the numbers on the graph-edges are the times of descent of the peak flood-waves, expressed in days.)

months, only one important conclusion can be made: if a very high water-level (maybe even higher than ever before) will occur in the Tisza at Szeged, then this can be expected with a higher probability in May and June than before May. The advanced season in itself does not mean a high flood-wave, but this is to be expected with the greatest certainty in the advanced season (presumably in the „special" situation in May-June which complements the effect of long and prolonged winter precipitation.

*

The great flood of the Tisza in 1970 was an instructive series of events which also provided incentives for the various sciences. It was possible to become reacquainted from new angles with this perhaps most loved of our rivers, which is certainly not easy for us to know as regards its entire behaviour, its calms and its caprices. However, the flood-level plaque erected in the main square of Szeged to commemorate the peak of the flood-wave no longer announces a catastrophe which has taken place, but instead a possibility of danger which was averted by technical skill and heroism. The Tisza was thus prevented from repossessing the Great Hungarian Plain, and Szeged was successfully savedfrom the threat of a repetition in 1970 of the flood disaster in 1879.

References

Andó, M. (1964): A DK-Alföld természetföldrajzi adottságainak jellemzése. (Characterization of the natural geographical features of the S.E. Great Hungarian Plain.) — Candidate's thesis.
Atlas Climatologic (1949) — Bucharest.

Bogdánfy, Ö. (1904): Hidraulika. (Hydraulics.) — Budapest. (Published by the author.)

Busacker, R. G. and Seaty, T. L. (1969): Véges gráfok és hálózatok (Finite graphs and networks). — Műszaki Könyvkiadó Budapest.

Erdős, F. (1920): Tisza-szabályozás (Regulation of the Tisza). — Publications of the Hungarian Engineering and Architecture Association. *54*, Nos. 5—11 (in instalments).

Iványi, B. (1948): A Tisza kisvízi szabályozása (Regulation of the shallow waters of the Tisza). Part III. — Vízügyi Közl. *4*, 428—429.

Korbély, J. (1915): Az árvizekről (Floods). — Vízügyi Közl. *1*.

Korbély, J. (1917): A Körösök és a Berettyó szabályozása (Regulation of the Körös rivers and the Berettyó). — Vízügyi Közl. *1*.

Morariu, T. and Savu, A. (1954): De situatia retelei hidrografice din Transilvania, Banat, Crisana si Maramures. — Editura Academiei Republicii Populare Ramane. Vol. I.

Németh, E. (1954): Hidrológia és hidrometria (Hydrology and hydrometry). — Tankönyv Kiadó, Budapest.

Országos Meteorológiai Intézet (National Meteorological Institute) (1970): Időjárási napi jelentés (Daily weather report).

Rumanian daily weather report (1970).